Multinationals and their role in green innovation

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DOES IT MAKE SENSE TO ASSOCIATE MULTINATIONALS TO GREEN INNOVATION?

Multinational enterprises and green innovation: 3 key facts

#1   Green innovation must accelerate rapidly

#2   Multinational enterprises (MNEs) are key players in global innovation

#3   The sustainability imperative is the main driver of new FDIs

#1 Green innovation must accelerate rapidly

- According to IEA (2021) most of global CO_2 reductions through **2030** come from technologies readily available;

- But **almost half of the reductions through 2050** will come from technologies that are currently at the demonstration or prototype phase.

Annual CO₂ emissions savings in the net zero pathway, relative to 2020

Legend: Behaviour changes | Technologies in the market | Technologies under development

#2 MNEs are key players in global innovation

- According to the 2023 Industrial R&D Investment Scoreboard the world top 2,500 companies have invested more than one trillion euros in R&D.

2500 companies

€1249.7 billion

| US 42.1% | EU 17.5% | China 17.8% | Japan 9.3% | Rest 13.2% |

US €526.5 bn   **EU** €219.2 bn   **China** €222.2 bn   **Japan** €116.2 bn   **Rest** €165.5 bn

CANADA 29
UK 95
SOUTH KOREA 47
CHINA 679
SWITZERLAND 52
US 827
EU 367
JAPAN 229
ISRAEL 29
INDIA 22
TAIWAN 77
AUSTRALIA 10

The 2023 Scoreboard comprises the top 2500 R&D investors in the world. Based in 42 countries, they invested a record amount of €1249.7 billion, approximately 86% of the world's business-funded R&D.

Location of the world's top 2500 R&D investing companies. The world map includes only territories with at least 10 companies.

#3   The sustainability imperative is the main driver of new FDIs

- Since 2010, while manufacturing investment stagnated across all industries, **the number of cross-border greenfield projects along the entire value chain of environmental technologies sectors has steadily increased.**

Exhibit 14
Investment in environmental technologies bucks the trend
Number of cross-border greenfield projects in environmental technologies (excluding services activities)

◯ CAGR

360	288	439	568	501	474	493	706
2016	2017	2018	2019	2020	2021	2022	2023

10%

Source: UNCTAD, based on information from the Financial Times Ltd, fDi Markets (www.fDimarkets.com).
Note: CAGR: Compound Annual Growth Rate.

How do MNEs contribute to green innovation?

Agenda

1. Identification of Green Foreign Direct Investments (GFDI)
2. GFDI and the green innovative capacity of MNEs
3. GFDI and the green innovative capacity of MNE subsidiaries
4. GFDI and green knowledge spillovers in host countries

Why a focus on Renewable Energies?

- According to IEA, in 2022, electricity and heat generation from fuel combustion accounted for 44% of global CO_2 emissions.

- Renewable energy sources generate electricity with little to no emissions, helping to reduce the overall carbon footprint.

Table 3.1. - Global CO2 emissions from fuel combustion

	1990	2000	2010	2022
Electricity and heat generation	37%	40%	41%	44%
Transport	22%	25%	23%	23%
Others	8%	7%	7%	7%
Industry	19%	16%	20%	18%
Buildings	13%	11%	9%	8%

Legend: ■ Buildings ■ Industry ■ Others ■ Transport ■ Electricity and heat generation

Source: International Energy Agency

1 Identification of Green Foreign Direct Investments

Our definition: Green foreign direct investment (FDI) are investments in activities related with renewable energies from firms holding at least one green patent.

1. Green patents (DOCDB families) in "*technologies or applications for mitigation or adaptation against climate change*" with a firm as applicant (Y02E: energy generation from renewable sources - wind, solar, hydro, geothermal, marine, waste, biofuel) (PATSTAT);

2. Green MNEs are companies with at least one green patent and one foreign subsidiary (ORBIS);

3. Textual analysis on foreign subsidiaries' business activity to identify production or distribution of renewable energies.

4. In GFDI, we distinguish between Green Acquisitions and greenfield investments (all the remaining GFDI) (CB ORBIS).

1261 Green FDI in 66 countries (1997-2020)

Green FDI

■	(49,189]
■	(22,49]
■	(14.5,22]
■	(11,14.5]
■	(7,11]
■	(4.5,7]
■	(2,4.5]
■	(1,2]
■	[1,1]
□	0

#2   GFDI and the green innovative capacity of MNEs

Green foreign direct investments and the deepening of capabilities for sustainable innovation in multinationals: Insights from renewable energy

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4 output variables

- *Greening effect*
  - *Green Intensity:* % of green patents in total investor' patent portfolio after the deal
  - *Green Specialization:* Herfindahl index measuring the concentration in green patents after the deal
- *Green innovativeness*
  - *Green Patents:* # of MNE's green patents after the deal (i.e., quantity of innovation)
  - *Forward citations:* # of forward citations to MNE's green patents after the deal (i.e., quality of innovation)

Methodology

1. Counterfactual sample of non-investors with similar *ex-ante* probabilities to undertake FDI

2. Propensity score matching Dif-in-Dif estimators with a sample including both investors and non-investors

$$\Delta y_{i,j,x,t+s} = \alpha + \beta\, FDI_{i,j,x,t} + \gamma_j + \delta_x + \vartheta_t + \varepsilon_{i,t},$$

where g_j, d_x, and q_t are fixed effects for industry, home country and deal year

s=0,**1,2,3,4,5**.

Greening Effect and Green Innovativeness

Table 3

Propensity score matching difference-in-difference estimators.

	t = 0	t = 1	t = 2	t = 3	t = 4	t = 5	#Obs.
Greening effect							
Green Intensity	0.0215	0.0522***	0.0517***	0.0366**	0.0234	0.0457***	5589
	(0.0138)	(0.0129)	(0.0146)	(0.0158)	(0.0174)	(0.0155)	
Green Specialization	0.0195	0.0549***	0.0575**	0.0552**	0.0328	0.0666***	5589
	(0.0206)	(0.0205)	(0.0237)	(0.0251)	(0.0257)	(0.0246)	
Green innovativeness							
Green Patents	0.1340***	0.2028***	0.2707***	0.3014***	0.3085***	0.3431***	5589
	(0.0411)	(0.0466)	(0.0582)	(0.0616)	(0.068)	(0.067)	
Forward Citations	0.0242	0.1134	0.1007	0.0483	0.0413	0.0681	5589
	(0.067)	(0.0730)	(0.0826)	(0.0830)	(0.0834)	(0.0755)	

Matching by kernel algorithm with common support.

Outputs equal to $\ln(1+Y_{t+s})-\ln(1+Y_{t-1})$, where $s = 0,1,2,3,4,5$.

All regressions include fixed effects for investors country, investor NACE 2-digit sector and year of investment. Standard errors are clustered at investor level and reported in parentheses.

* p-value< 0.10, ** p-value< 0.05, *** p-value 0.010.

Greening effect

- Green intensity: There is an increase in the share of green patents within the MNEs' total patent portfolio in the first five years following the investment.

- Specialization: MNEs are increasing their specialization in technologies, such as solar or wind, where they already hold most of their green patents.

Green innovativeness

- Number of green patents increases in MNEs (while forward citations has a positive but not significant impact)

Key takeaways

- There is a greening effect, as MNEs are increasingly innovating in green technologies after undertaking GFDI.

- This is positive news for the green transition, as MNEs are enhancing green innovations, and contribute to make green technologies more efficient, affordable, and accessible.

Do green foreign direct investments increase the innovative capability of MNE subsidiaries?

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RQ To what extent are MNEs contributing to increase the green innovative capabilities of their subsidiaries vis-à-vis domestic companies?

Methodology

- **Output variables**
  - # of green patents (DOCDB families) up to 5 years after the investment
  - # forward citations (average) to green patents up to 5 years after the investment
  - Patents are attributed to subsidiaries if at least one inventor is from the same country of the subsidiary (Stiebale, 2016): 1,410 SUBSIDIARIES' PATENTS IN RE

- **Main independent variable:** Dummy 1= MNE subsidiary 0 = domestic company

- **Moderating factors:** Host country-specific characteristics (GDP per capita; # of patents per capita; oil rents %GDP)

- **Counter sample:** 6,276 DOMESTIC COMPANIES **with at least one patent in RE technologies** (in the same sectors/countries of the subsidiaries)

- **Negative binomial model** (Piperopoulos et. al., 2018) with **fixed effects** (NACE 2-digit sector and deal year) and several controls (SIZE, AGE, PRE-DEAL KNOWLEDGE BASE)

Table 2
Full sample.

	OUTPUT: # green patents						OUTPUT: # forward citations to green patents					
	t (1)	t + 1 (2)	t + 2 (3)	t + 3 (4)	t + 4 (5)	t + 5 (6)	t (7)	t + 1 (8)	t + 2 (9)	t + 3 (10)	t + 4 (11)	t + 5 (12)
FDI SUBSIDIARY	−0.859*** (0.262)	−0.049 (0.262)	0.188 (0.249)	0.377 (0.263)	0.705*** (0.245)	0.552** (0.274)	1.167*** (0.375)	1.154*** (0.352)	1.202*** (0.399)	1.510*** (0.361)	2.115*** (0.357)	2.187*** (0.376)
PATENT PORTFOLIO STOCK LAG 1 (LN)	−0.690** (0.306)	−0.614*** (0.171)	−0.626*** (0.211)	−0.145 (0.144)	−0.518** (0.208)	−0.172 (0.166)	−1.029*** (0.187)	−1.056*** (0.167)	−1.099*** (0.260)	−1.049*** (0.365)	−1.026*** (0.234)	−0.666*** (0.257)
AGE (LN)	−0.314*** (0.071)	−0.249*** (0.071)	−0.189*** (0.072)	−0.244*** (0.074)	−0.087 (0.072)	−0.156* (0.086)	−0.072 (0.085)	−0.414*** (0.077)	−0.281*** (0.087)	−0.226** (0.090)	−0.125 (0.092)	−0.003 (0.097)
MIDDLE SIZE	0.093 (0.165)	0.173 (0.182)	0.066 (0.169)	0.138 (0.181)	0.105 (0.208)	0.934*** (0.221)	−0.127 (0.204)	−0.150 (0.214)	0.021 (0.230)	−0.040 (0.249)	0.015 (0.244)	0.815*** (0.264)
LARGE_SIZE	0.350* (0.188)	0.088 (0.200)	0.308 (0.199)	0.398** (0.193)	0.405** (0.206)	1.064*** (0.241)	−0.313 (0.232)	0.067 (0.241)	−0.487** (0.230)	−0.154 (0.280)	0.507** (0.250)	0.741** (0.345)
COUNTRY GDP PC (LN)	0.106 (0.068)	0.010 (0.063)	0.029 (0.069)	0.150* (0.077)	−0.004 (0.072)	−0.081 (0.074)	0.250*** (0.083)	0.305*** (0.083)	0.255*** (0.089)	0.458*** (0.104)	0.360*** (0.083)	0.228** (0.092)
COUNTRY PATENT PC (LN)	0.131 (0.148)	0.466*** (0.154)	0.265 (0.166)	0.422** (0.170)	0.764*** (0.195)	1.062*** (0.206)	0.384* (0.202)	−0.032 (0.218)	0.242 (0.248)	−0.165 (0.196)	0.353 (0.242)	0.921*** (0.260)
OIL RENTS (% GDP)	−0.049 (0.043)	−0.061 (0.038)	−0.082* (0.042)	−0.063 (0.053)	−0.023 (0.038)	0.011 (0.055)	−0.145*** (0.046)	−0.074* (0.043)	−0.156*** (0.050)	−0.012 (0.068)	−0.064 (0.043)	0.192 (0.133)
INDUSTRY FE	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
DEAL YEAR FE	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
CONSTANT	−19.082	−20.876*** (1.222)	−21.553 .	−22.229 .	−20.192*** (0.858)	−20.596*** (1.914)	−21.540*** (1.409)	−27.152 (9090.162)	−36.194 (8447873.262)	−31.572 .	−23.094*** (0.613)	−27.666 (125.124)
LNALPHA	2.462*** (0.164)	2.838*** (0.101)	2.788*** (0.107)	2.870*** (0.113)	2.983*** (0.112)	3.171*** (0.110)	4.048*** (0.071)	4.087*** (0.072)	4.148*** (0.081)	3.996*** (0.082)	4.044*** (0.084)	4.177*** (0.097)
OBSERVATIONS	7331	7331	7331	7331	7331	7331	7331	7331	7331	7331	7331	7331

FDI subsidiaries = 1,055. # Domestic companies = 6,276. Robust standard errors are in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$".

Table 3
Interaction terms (full sample).

	OUTPUT: # green patents						OUTPUT: # forward citations to green patents					
	t (1)	t + 1 (2)	t + 2 (3)	t + 3 (4)	t + 4 (5)	t + 5 (6)	t (7)	t + 1 (8)	t + 2 (9)	t + 3 (10)	t + 4 (11)	t + 5 (12)
FDI SUBSIDIARY	−2.042** (0.864)	−1.498* (0.845)	−1.182 (1.202)	0.017 (0.734)	0.143 (0.574)	0.242 (0.593)	1.730** (0.789)	2.486*** (0.818)	2.081** (0.922)	3.302*** (0.791)	3.251*** (0.686)	2.770*** (0.650)
PATENT PORTFOLIO STOCK LAG 1 (LN)	−0.728** (0.293)	−0.746*** (0.194)	−0.699*** (0.242)	−0.169 (0.150)	−0.575*** (0.215)	−0.255 (0.178)	−0.978*** (0.181)	−1.018*** (0.171)	−1.030*** (0.265)	−0.986*** (0.311)	−1.343*** (0.247)	−0.826*** (0.237)
AGE (LN)	−0.323*** (0.070)	−0.254*** (0.075)	−0.187** (0.077)	−0.239*** (0.073)	−0.087 (0.071)	−0.175** (0.085)	−0.077 (0.084)	−0.419*** (0.077)	−0.297*** (0.087)	−0.252*** (0.090)	−0.211** (0.093)	−0.042 (0.097)
MIDDLE SIZE	0.094 (0.163)	0.153 (0.180)	0.036 (0.165)	0.123 (0.181)	0.073 (0.204)	0.945*** (0.219)	−0.104 (0.205)	−0.122 (0.210)	0.037 (0.232)	−0.087 (0.246)	0.145 (0.240)	0.848*** (0.269)
LARGE SIZE	0.368** (0.186)	0.121 (0.202)	0.331* (0.200)	0.403** (0.193)	0.435** (0.208)	1.162*** (0.240)	−0.298 (0.235)	0.139 (0.246)	−0.461** (0.230)	−0.136 (0.278)	0.634** (0.255)	0.895*** (0.339)
COUNTRY GDP PC (LN)	0.062 (0.068)	−0.035 (0.061)	−0.030 (0.064)	0.115 (0.075)	−0.028 (0.078)	−0.070 (0.083)	0.331*** (0.087)	0.403*** (0.088)	0.324*** (0.098)	0.496*** (0.119)	0.577*** (0.093)	0.440*** (0.117)
COUNTRY PATENT PC (LN)	0.101 (0.148)	0.360** (0.156)	0.192 (0.168)	0.395** (0.174)	0.648*** (0.200)	0.892*** (0.211)	0.301 (0.199)	−0.157 (0.219)	0.166 (0.250)	−0.084 (0.202)	0.070 (0.246)	0.491* (0.262)
OIL RENTS (%GDP)	−0.037 (0.043)	−0.050 (0.039)	−0.079* (0.045)	−0.054 (0.055)	−0.038 (0.042)	0.003 (0.056)	−0.153*** (0.049)	−0.049 (0.044)	−0.143*** (0.053)	0.006 (0.070)	−0.079 (0.048)	0.139 (0.171)
FDI SUBSIDIARY * COUNTRY GDP PC	**0.334 (0.288)**	**0.254 (0.240)**	**0.277 (0.344)**	**0.083 (0.221)**	**−0.079 (0.180)**	**−0.263 (0.179)**	**−0.390* (0.224)**	**−0.660*** (0.219)**	**−0.445* (0.249)**	**−0.233 (0.241)**	**−1.292*** (0.220)**	**−0.966*** (0.189)**
FDI SUBSIDIARY * COUNTRY PATENT PC	**0.471 (0.925)**	**2.111** (0.900)**	**1.530* (0.896)**	**0.548 (0.770)**	**2.030** (0.844)**	**2.918*** (0.869)**	**1.286 (1.156)**	**2.467** (1.123)**	**1.403 (1.261)**	**−1.777 (1.091)**	**6.497*** (1.076)**	**5.463*** (1.137)**
FDI SUBSIDIARY * COUNTRY OIL RENTS	**−0.070 (0.115)**	**−0.086 (0.127)**	**−0.024 (0.138)**	**−0.109 (0.120)**	**0.074 (0.099)**	**−0.071 (0.147)**	**−0.070 (0.206)**	**−0.604*** (0.204)**	**−0.253 (0.190)**	**−0.858*** (0.247)**	**−0.064 (0.168)**	**−0.193 (0.237)**
INDUSTRY FE	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
DEAL YEAR FE	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
CONSTANT	−20.379 .	−21.262*** (2.125)	−19.904*** (1.223)	−21.323** (9.381)	−20.276*** (0.975)	−20.766 .	−22.385*** (3.576)	−24.177 .	−35.701 .	−19.287*** (0.834)	−24.453*** (0.987)	−32.564 (7659.261)
LNALPHA	2.456*** (0.160)	2.816*** (0.097)	2.766*** (0.111)	2.865*** (0.115)	2.977*** (0.112)	3.160*** (0.110)	4.043*** (0.071)	4.072*** (0.072)	4.139*** (0.080)	3.985*** (0.082)	3.991*** (0.082)	4.120*** (0.098)
OBSERVATIONS	7331	7331	7331	7331	7331	7331	7331	7331	7331	7331	7331	7331

FDI subsidiaries = 1,055. # Domestic companies = 6,276. Robust standard errors are in parentheses. * p < 0.10, ** p < 0.05, *** p < 0.01″.

Main findings

- Subsidiaries outperform comparable domestic companies with respect to # of green patents & # of forward citations

  → green innovative advantage with respect to domestic companies

- **Interaction terms**

  - **GDP per capita:** relative to domestic companies the subsidiaries of MNEs are more innovative when the GDP per capita is lower

    → in less developed countries being a subsidiary, it really makes a difference!

  - **Patents per capita:** the advantage of being a subsidiary is larger in more innovative countries → better absorptive capacity

  - **Oil Rents (% GDP):** in oil countries, subsidiaries engage less in green innovative activity → the resource curse hypothesis.

Key takeaways

- Green MNEs subsidiaries are more innovative than domestic firms (with similar characteristics).

- The green innovative advantage is larger in less developed countries, with high levels of domestic innovative capacity (e.g., China and India).

 # 4 GFDI and Green Knowledge Spillovers in Host Economies

with Vito Amendolagine & Dalila Ribaudo

Green knowledge spillovers

- Green technologies generate larger knowledge spillover than non-green technologies due to their novelty, pervasiveness, and diversity (Barbieri et al, 2020; Dechezleprêtre et al., 2014)
  - Green inventions receive 43% more citations than dirty inventions (Dechezlepretre et al, 2017).
- Technological Impact: green technologies tend to be more complex and radical than non-green ones, having a greater impact on subsequent inventions (Fusillo, 2023)

How to measure green knowledge spillovers

- **Patent citations are a measure of knowledge spillovers** because indicate a flow of knowledge that contributes to the development of new ideas (Jaffe, 1993; Jaffe & Trajtenberg 1999).

- Knowledge spillovers from FDIs are measured by patent citations, considering how inventors learn from the research outcomes of others' projects (Branstetter, 2006).

- The intuition is that MNEs' patents can activate cross-border knowledge spillovers and enhance innovation capacity (i.e., patents) in host countries.

- **Forward citations to green patents owned by green MNEs and their green subsidiaries** (excluding self-citations): for each investor i in every year t, we consider all the countries j where there are **citations to its green patents,** according to the address of the first inventor.

An example

- α green patents are cited in 43 countries;

- From 1997 to 2020 α has undertaken 37 green FDIs in 21 countries;

- In 1998
  - In Country A there are 2 FDIs and 3 citations to α green patents.
  - In Country B there are no FDIs and 2 citations to α green patents.

Investor (i)	Country (j)	Year (t)	#Forward Citations	FDI
α	A	1997	1	0
α	A	1998	3	2
α	A	....		...
α	A	2020	7	0
α	B	1997	1	0
α	B	1998	2	0
α	B	....		..
α	B	2020	4	0

Countries with a higher volume of green FDIs—such as the USA, Germany, the UK, China, and India—also tend to cite more foreign investors' green patents.

Figure 3. Green FDI and Knowledge Spillovers

Source: Authors' elaboration

MNEs green patents forward citations in 94 countries

Foreign forward citations to MNEs' green patents

(6847,66233]
(2396,6847]
(276,2396]
(145,276]
(49,145]
(34,49]
(14,34]
(9,14]
[1,9]
0

$$Forward\ Citations_{i,j,t} = \alpha + \beta_1 Cumulative\ Green\ Patents_{i,t} + \beta_2 Green\ Patents\ Age_{i,t} + \beta_3 FDI_{i,j,t-s} + \gamma_i + \delta_j + \theta_t + \epsilon_{i,t,j}$$

Dependent Variable: # of forward citations in country *j* (where the first investor resides) to all green patents of the investor *i* (cumulated up to year *t)*

Main independent variables:

- Dummy variable: 1 in country *j* where the investor i has at least one investment (year of the first investment), 0 otherwise (extensive margin)

  - *RQ1 Does <u>the presence of green foreign direct investment</u> of a particular investor positively influence green knowledge spillovers in host countries?*

- # of green FDIs by investor *i* in country *j* at year *t* (intensive margin)

  - *RQ2 Does the <u>number of green foreign direct investments</u> of a particular investor positively influence green knowledge spillovers in host countries?*

Negative binomial estimation with investor, host country & year FE and errors clustered at the investor level
s=0,1,2,3

- Green FDIs enhance green technological spillovers both at the intensive and extensive margin;

- While the initial green FDI by a given investor can trigger positive knowledge spillovers, these are more likely to occur with a greater number of investments by the same investor.

Table 1. Green FDI and Knowledge Spillover

#Forward Citations	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Extensive Margin				*Intensive Margin*			
Cumulative Green Patents	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Green Patents Age	1.281***	1.283***	1.276***	1.259***	1.279***	1.281***	1.274***	1.257***
	(0.097)	(0.098)	(0.097)	(0.096)	(0.097)	(0.098)	(0.098)	(0.097)
Green FDI Dummy	0.122*							
	(0.068)							
Green FDI Dummy (t-1)		0.083						
		(0.064)						
Green FDI Dummy (t-2)			0.110**					
			(0.055)					
Green FDI Dummy (t-3)				0.122**				
# Green FDI					0.134**			
					(0.054)			
# Green FDI (t-1)						0.121**		
						(0.055)		
# Green FDI (t-2)							0.123***	
							(0.046)	
# Green FDI (t-3)								0.128***
								(0.050)
F.E. (target country, investor, year)	YES	YES	YES	YES	YES	YES	YES	YES
Obs.	80856	77487	74118	70749	81240	77855	74470	71085

RQ2: *Are the effects of green FDIs on green knowledge spillovers dependent on the mode of entry?*

- The effect is stronger for acquisitions than greenfield investments

- The knowledge transferred by foreign investors is more readily absorbed in the host country, as it accumulates with the knowledge already present in the acquired local subsidiary.

Table 5. Green FDI and Knowledge Spillover by FDI Entry Mode: Intensive Margin

	(1)	(2)	(3)	(4)
Cumulative Green Patents	0.000	0.000	0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)
Green Patents Age	1.280***	1.475***	1.469***	1.257***
	(0.097)	(0.083)	(0.082)	(0.097)
# Green Greenfield FDI	0.071			
	(0.071)			
# Green Acquisitions	0.223***			
	(0.080)			
# Green Greenfield FDI (lag 1)		0.123*		
		(0.065)		
# Green Acquisitions (lag 1)		0.296***		
		(0.090)		
# Green Greenfield FDI (lag 2)			0.156***	
			(0.056)	
# Green Acquisitions (lag 2)			0.265***	
			(0.078)	
# Green Greenfield FDI (lag 3)				0.107*
				(0.062)
# Green Acquisitions (lag 3)				0.164**
				(0.072)
Constant	-8.367***	-441.272***	-436.939***	-3.195***
	(0.474)	(10.878)	(10.866)	(0.403)
Observations	81240	77855	74470	71085

RQ3: Are the effects of green FDIs on green knowledge spillovers dependent on the characteristics of renewable energy technologies? Focus on Wind & Solar

Table 2. Green FDI and Knowledge Spillover: Wind Energy

# Forward Citations	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Extensive Margin				*Intensive Margin*			
Cumulative Green Patents	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Green Patents Age	1.036***	1.039***	1.039***	1.035***	1.055***	1.058***	1.057***	1.055***
	(0.101)	(0.101)	(0.101)	(0.101)	(0.100)	(0.101)	(0.100)	(0.100)
Green FDI Dummy	0.083							
	(0.112)							
Green FDI Dummy (t-1)		0.129						
		(0.093)						
Green FDI Dummy (t-2)			0.180**					
			(0.075)					
Green FDI Dummy (t-3)				0.142**				
				(0.072)				
# Green FDI					0.144**			
					(0.067)			
# Green FDI (t-1)						0.163***		
						(0.055)		
# Green FDI (t-2)							0.153***	
							(0.051)	
# Green FDI (t-3)								0.133***
								(0.051)
F.E. (target country, investor, year)	YES	YES	YES	YES	YES	YES	YES	YES
Obs.	28272	27094	25916	24738	28104	26933	25762	24591

Table 3. Green FDI and Knowledge Spillover: Solar PV Energy

# Forward Citations	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Extensive Margin				*Intensive Margin*			
Cumulative Green Patents	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Green Patents Age	1.235***	1.245***	1.245***	1.231***	1.250***	1.260***	1.258***	1.243***
	(0.115)	(0.116)	(0.116)	(0.116)	(0.114)	(0.115)	(0.115)	(0.115)
Green FDI Dummy	0.155*							
	(0.089)							
Green FDI Dummy (t-1)		0.077						
		(0.083)						
Green FDI Dummy (t-2)			0.088					
			(0.070)					
Green FDI Dummy (t-3)				0.107				
				(0.065)				
# Green FDI					0.136**			
					(0.061)			
# Green FDI (t-1)						0.109		
						(0.071)		
# Green FDI (t-2)							0.095	
							(0.065)	
# Green FDI (t-3)								0.092
								(0.061)
F.E. (target country, investor, year)	YES	YES	YES	YES	YES	YES	YES	YES
Obs.	53016	50807	48598	46389	53112	50899	48686	46473

Wind and Solar Technologies

- Wind: significant for greenfield investments and acquisitions;

- Solar: weaker effect and limited to acquisitions.

- Green technologies are characterized by a different degree of maturity: solar technology is more mature than wind (Noailly & Shestalovaa, 2017).

**Knowledge is more tacit in wind
and more codified in solar!**

RQ4: *Are the effects of green FDIs on green knowledge spillovers dependent on the <u>level of development in the host countries</u>?*

- Green technological spillovers are stronger in countries with lower GDP per capita (at the intensive margin) (as in Amendolagine et al, 2023)

- In less developed countries MNES can really make a difference in terms of green innovation!

Table 6. Green FDI and Knowledge Spillovers: Host Country Development Level

# Forward Citations	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Cumulative Green Patents	0.000	0.000	0.000	0.000	-0.000	-0.000	-0.000	-0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Green Patents Age	1.280***	1.281**	1.274***	1.258***	1.310***	1.313***	1.306***	1.289***
	(0.096)	(0.097)	(0.097)	(0.096)	(0.099)	(0.100)	(0.100)	(0.098)
Green FDI Dummy	0.136				0.309***			
	(0.090)				(0.067)			
Green FDI Dummy (lag 1)		0.082				0.233***		
		(0.089)				(0.064)		
Green FDI Dummy (lag 2)			0.124				0.227***	
			(0.085)				(0.067)	
Green FDI Dummy (lag 3)				0.133*				0.253***
				(0.079)				(0.068)
Green FDs Dummy * GDP per capita	-0.000							
	(0.000)							
Green FDI Dummy * GDP per capita (lag 1)		-0.000						
		(0.000)						
Green FDI Dummy * GDP per capita (lag 2)			-0.000					
			(0.000)					
Green FDI Dummy * GDP per capita (lag 3)				-0.000				
				(0.000)				
# Green FDI * GDP per capita					-0.000**			
					(0.000)			
# Green FDI * GDP per capita (lag 1)						-0.000		
						(0.000)		
# Green FDI * GDP per capita (lag 2)							-0.000*	
							(0.000)	
# Green FDI * GDP per capita (lag 3)								-0.000**
								(0.000)
F.E. (target country, investor, year)	YES	YES	YES	YES	YES	YES	YES	YES
Observations	79843	76562	73281	7000	73986	70898	67810	64722

Placebo test

Non-green FDI (at the extensive margin) from the same investor i in country j does not significantly increase the number of forward citations to investor i's green patents.

Table 8. Non-Green FDI and Knowledge Spillovers: Extensive Margin

# Forward Citations	(1)	(2)	(3)	(4)
Cumulative Green Patents	0.000	0.000	0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)
Green Patents Age	1.277***	1.278***	1.270***	1.253***
	(0.097)	(0.098)	(0.098)	(0.096)
Non-Green FDIs Dummy	0.185			
	(0.130)			
Non-Green FDIs Dummy (t-1)		0.231		
		(0.145)		
Non-Green FDIs Dummy (t-2)			0.258	
			(0.158)	
Non-Green FDIs Dummy (t-3)				0.221
				(0.197)
F.E. (target country, investor, year)	YES	YES	YES	YES
Observations	80712	77349	73986	70623

Test for reverse causality

- We consider the possibility that green FDI may be more attracted to countries where patents held by investors (and their subsidiaries) are more cited, in other words to countries with more innovative companies.

- The number of forward citations is weakly associated with the number of green FDI at 10% significance level at lag 0 and 3.

- When green FDI is measured with the dummy variable, the results are not significant.

Table 10. Test for Reverse Causality

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Output: # Green FDI				Output: FDI dummy			
Cumulative Green Patents	-0.000	-0.000	-0.000	-0.000*	-0.000*	-0.000**	-0.000**	-0.000***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Green Patents Age	-0.520	-0.390	-0.402	-0.301	-0.499	-0.403	-0.384	-0.355
	(0.337)	(0.345)	(0.351)	(0.354)	(0.379)	(0.392)	(0.401)	(0.407)
# Forward Citations	0.002*				-0.000			
	(0.001)				(0.002)			
# Forward Citations (lag 1)		0.002				-0.001		
		(0.001)				(0.003)		
# Forward Citations (lag 2)			0.003				-0.002	
			(0.002)				(0.003)	
# Forward Citations (lag 3)				0.003*				-0.003
				(0.002)				(0.004)
F.E. (target country, investor, year)	YES	YES	YES	YES	YES	YES	YES	YES
Observations	81240	77855	74470	71085	52624	48114	45171	42240

Key takeaways

- Green FDIs (and only green FDIs) are important drivers of innovation in green renewable energies;

- Their impact is not limited to MNEs' boundaries (Amendolagine et al., 2021) and their subsidiaries (Amendolagine et al., 2023) but they also increase green knowledge spillovers in the host countries, enhancing domestic green innovative activities;

- Their impact is stronger in a) acquisitions; b) wind industry; and c) lower-income countries

Policy implications

- Countries can enhance their green innovative capacity by attracting green FDI.

- The increasing adoption of screening investment frameworks may be detrimental to green innovation that can speed up the green transformation worldwide.

- Policies aimed at attracting green FDI should come together with measures that encourage knowledge spillovers from MNE subsidiaries to domestic companies, such as local content requirements and training programs for the local workforce.

- Green technology transfer should be prioritized in WTO and TRIMS agreements, recognizing the public goods nature of green technologies and facilitating their global diffusion through FDI.

Amendolagine, V., Lema, R., & Rabellotti, R. (2021). Green foreign direct investments and the deepening of capabilities for sustainable innovation in multinationals: Insights from renewable energy. *Journal of Cleaner Production*, *310*, 127381.

Amendolagine, V., Hansen, U. E., Lema, R., Rabellotti, R., & Ribaudo, D. (2023). Do green foreign direct investments increase the innovative capability of MNE subsidiaries?. *World Development*, *170*, 106342.

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